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Fast task-irrelevant perceptual learning is disrupted by sudden onset of central task elements

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ABSTRACT

The basic phenomenon of task-irrelevant perceptual learning (TIPL) is that the stimulus features of a subject's task will be learned when they are consistently presented at times of reward or behavioral success. Recent progress in studies of TIPL has been made by the discovery of a fast form of TIPL (fast-TIPL), which can be observed with as little as a single trial of exposure. In the present study, we investigated the task-conditions required to observe fast-TIPL. We had participants perform a target detection task at fixation while scenes to memorize were presented peripherally. In some experiments the target was presented in a sequence of distractors (Experiments 2 and 4) and in others alone (Experiments 1 and 3). In each experiment we assessed whether learning for target-paired scenes was greater than that of nontarget-paired scenes. The results indicated an enhanced memorization for scenes paired with the targets in the experiments where the target was presented with distractors, but not in the experiments where distractors were not presented. We hypothesized that without the presentation of distractors the onset of the target was sudden and this may have exogenously drawn attention to the center of the display disrupting TIPL. This sudden onset hypothesis was experimentally confirmed in Experiment 5. We conclude that fast-TIPL, with its rapid time-course, and its production of learning for supraliminally presented stimuli, shows great promise as an efficient paradigm through which to understand mechanisms of learning.

1. Introduction

Our perceptual systems receive abundant information from the environment. However, only some of this information is processed to the degree that it can later be reported. One framework for learning is that behaviorally relevant information will be best encoded. That is, that we do not simply learn aspects of the world based upon their statistics of occurrence, but instead that learning is gated by processes such as attention and reinforcement such that we learn best what is most relevant. In this framework, the phenomenon of task-irrelevant perceptual learning (TIPL) (Seitz & Dinse, 2007; Seitz & Watanabe, 2005, 2009) has captured a growing interest in the field of perceptual learning and has led to specific predictions regarding how reinforcement from task-performance (Seitz, Lefebvre, et al., 2005; Seitz & Watanabe, 2003) or delivery of reward (Seitz, Kim, & Watanabe, 2009) can lead to better processing of stimuli, even when they are task-irrelevant.

The basic phenomenon of TIPL (Seitz & Watanabe, 2009) is that the stimulus features of a subject's task are learned when they are consistently presented at times of reward or behavioral success. In the standard TIPL paradigm (Seitz & Watanabe, 2003), subjects have to conduct a relevant task, for example detecting a target in a rapid serial visual presentation (RSVP) of stimuli (e.g. light-gray letters among black letters), while irrelevant stimuli are consistently paired with the targets of the RSVP task (Seitz & Watanabe, 2008). The results of these procedures show that subjects learn, and become better at detecting or discriminating, the target-paired task-irrelevant stimuli (Watanabe, Nanez, & Sasaki, 2001). Seitz and Watanabe (2003) found that TIPL occurred as the result of temporal pairing between the presentation of a task-irrelevant, motion stimulus and a task-target. This result suggests that perceptual learning of the irrelevant information is not passive, but occurs for information that is consistently presented at behaviorally relevant times. Thus, TIPL could be related to a reward-based learning mechanism that reinforces perceptual information presented during a rewarding event (Seitz & Watanabe, 2005), even when that information is not expected nor explicitly identified. By now TIPL has been found for motion processing (Watanabe et al., 2002), orientation processing (Nishina et al., 2007), critical flicker fusion thresholds (Seitz, Nanez, et al., 2005, 2006), contour integration (Rosenthal & Humphreys, 2010), auditory formant processing (Seitz et al., 2010), and phonetic processing (Vlahou, Seitz, & Protopapas, 2009) and thus appears to be a basic mechanism of learning in the brain that spans multiple levels of processing and sensory modalities.

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Recent progress in studies of TIPL has been made by a number of labs with the demonstration of a fast form of TIPL (fast-TIPL) that can be found with as little as a single trial of exposure (Lin et al., 2010; Swallow & Jiang, 2010, 2011). These studies show that visual memory is enhanced for stimuli (photographs of urban and natural scenes or faces) that are paired with the targets of an RSVP task (white stimulus among black stimuli). Notably, in these experiments, the enhancement of visual memory is found for stimuli that are irrelevant to the RSVP tasks. Compared to slow-TIPL, in which, subjects do not have any task to perform concerning the stimuli presented alongside the RSVP task (i.e. moving dots) – thus the paired-stimuli are totally irrelevant to the subjects – in fast-TIPL, subjects are informed that they have to memorize the stimuli presented alongside the RSVP task (i.e. images of scenes or faces). Thus in fast-TIPL, compared to slow-TIPL, these paired images are important to the subjects, however, they are still irrelevant to the RSVP task in the sense that the paired images give absolutely no cue to answer to the RSVP task. Explanations for fast-TIPL mirror those of slow-TIPL. For example, Lin et al. (2010) suggest a mechanism where traces of visual scenes are automatically encoded into memory at behaviorally relevant points in time regardless of the spatial focus of attention. Swallow and Jiang (2010) suggest that detecting a target in one task may induce an "attentional boost" at the moment in time that the target appeared that facilitates the processing and encoding of information into memory. While the enhanced memorization found in these studies of fast-TIPL may involve some differences in underlying processes from the low-level perceptual learning that has been the primary focus of studies of slow-TIPL, the strong parallels between the experimental paradigms and results suggests that there are overlapping mechanisms, and we thus suggest that fast-TIPL and slow-TIPL are related phenomena.

The studies of fast-TIPL make a number of findings regarding the processes of learning. First, they show that TIPL can occur on the time scale of a single trial, rather than the many days of exposure typically required to observe slow-TIPL. Second, they show that processing of stimuli that are relevant to the subject (although not relevant to the RSVP task), and not only irrelevant stimuli, can be enhanced through TIPL. Third, they show that TIPL can occur for salient stimuli. Consequently, the use of such fast-TIPL procedures can lead to more efficient methods by which to investigate the processes involved in TIPL and to the generalization of the TIPL paradigm to study learning of stimuli that are task-relevant (Seitz & Watanabe, 2008).

While these recent studies of fast-TIPL by Lin et al. (2010) and Swallow and Jiang (2010) are promising in understanding the mechanisms underlying TIPL, their procedures are quite different. In Lin et al. (2010), in each trial a RSVP stream of 15 dark letters (distractors) and 1 white letter (target) was each paired with a unique image. At the end of each trial, participants reported the target letter and whether they recognized a test image (either a target-paired image, a distractor-paired image, or an image not presented in that trial). In the procedure used by Swallow and Jiang (2010), participants were asked to memorize a serie of images paired either with white squares, to which they gave an immediate response, or black squares, which were ignored. A memory test was conducted only after the completion of 10 blocks, each containing approximately 170 images. Given these procedural differences in the study of fast-TIPL it is unclear the important aspects of these tasks that give rise to learning.

In the current study, we looked to determine the key task conditions that would lead to fast-TIPL. We started (Experiment 1) with a simple detection task (e.g. Swallow & Jiang, 2010) without any distractors and with a scene recognition task after each trial (e.g. Lin et al., 2010). With this procedure, we expected to replicate results obtained in previous studies of fast-TIPL, that is an enhanced memorization for information presented with task-targets. However, we found that this procedure failed to produce fast-TIPL. Instead, we found that the inclusion of distractors into the design was needed to get enhanced memorization during target-processing (Experiment 2). We then replicated these findings (Experiments 3 and 4) by showing that the presence of distractors was also needed to find fast-TIPL in the context of a RSVP letter identification task (Lin et al., 2010; Seitz & Watanabe, 2003; Watanabe et al., 2001). In Experiment 5, we demonstrate that these results can be explained by the sudden onset of the target, which disrupted the observation of TIPL in the absence of distractors.

2. Experiment 1

In this first experiment, we examined whether enhanced memorization would occur for scene images paired with targets of a simple detection task.

2.1. Methods

Sixteen participants (19 y.o. ± 1 y.o.; 10 females, 6 males) gave informed consent to participate in this experiment, which was approved by the University of California, Riverside. All participants reported normal or corrected-to-normal visual acuity and received course credit and financial compensation for the 1-h session. Prior to testing, participants were familiarized with the 192 scenes that were to be used in the experiment by viewing each image for 2 s. After this, participants performed a practice block of 24 trials. Each participant was then tested for a total of 240 trials, in 10 blocks of 24 trials. Blocks were separated by brief breaks.

2.2. Apparatus and stimuli

An Apple Mac Mini running Matlab (Mathworks, Natick, MA) and Psychtoolbox Version 3 (Brainard, 1997; Pelli, 1997) was used for stimulus generation and experiment control. Stimuli were presented on a 22″ monitor with resolution of 1680×1050 resolution, and a refresh rate of 60 Hz. Participants sat with their eyes approximately 60 cm from the screen. The backgrounds of all displays were a mid-gray (luminance of 92 cd/m^2). Display items consisted of 192, 700×700 pixel (18.3° of visual angle), photographs depicting natural or urban scenes from eight distinct categories (i.e., mountains, cityscapes, etc.). Scenes were obtained from the LabelMe Natural and Urban Scenes database (Oliva & Torralba, 2001) at 250×250 pixels of resolution, then up-sampled to 700×700 pixels of resolution. The average luminance of all images was 79 cd/m^2 (standard deviation of 29).

2.3. Procedure

Each trial began with the presentation of a black fixation cross (0.3° of visual angle) for 450 ms. This presentation was followed by a rapid sequence of 16 full-field scenes. Each scene was presented for 133 ms, followed by an ISI of 367 ms, during which only the fixation cross was presented, for a SOA of 500 ms (Fig. 1A).

2.3.1. White square detection task

A gray aperture (1° of visual angle and luminance of 92 cd/m^2) was presented in the center of each scene, thus centered in the middle of the screen. In each trial, a fixation cross was presented at central fixation in the middle of the gray aperture for 15 scenes, and a white square (0.75° of visual angle and luminance of 251 cd/m^2) was presented in the middle of the gray aperture for 1 scene. The white square had the same onset and offset time as the image with which it was paired. The white square could only appear with

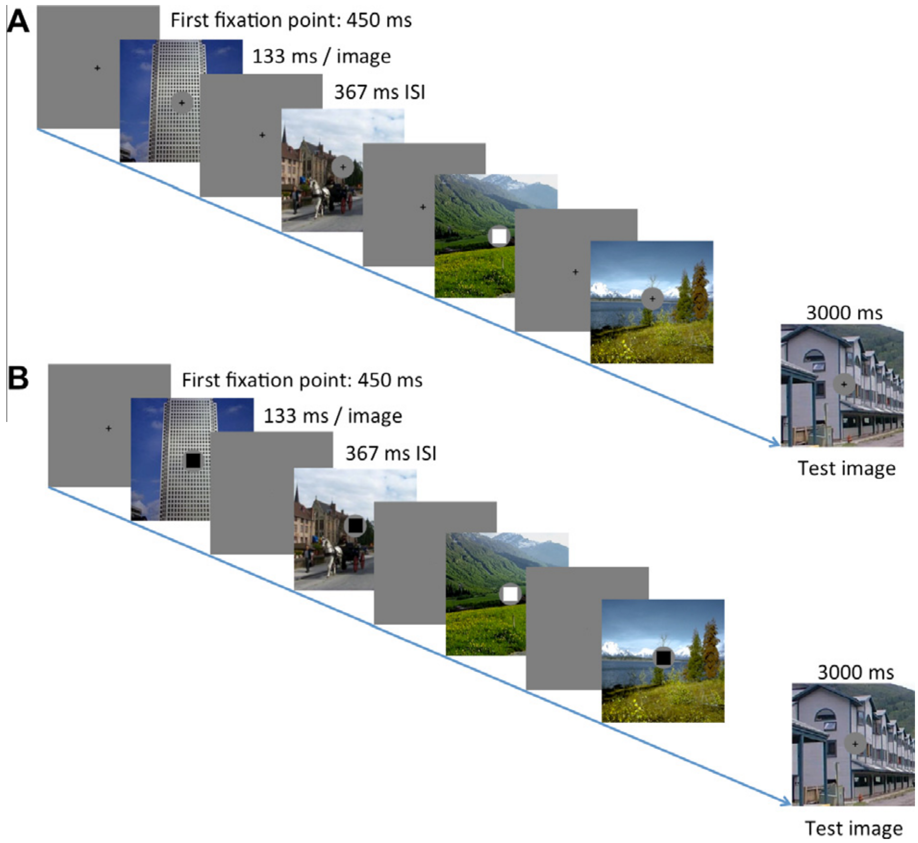

Fig. 1. Design of Experiments 1 and 2. (A) Experiment 1, In each trial, participants had to rapidly press a key when the white square appeared while also memorizing 16 scenes presented in RSVP. Experiment 3 used a similar display configuration, however, letter was used instead of square. (B) Experiment 2, In each trial, participants had to rapidly press a key when the white square appeared while also memorizing 16 scenes presented in RSVP. Experiment 4 used a similar display configuration, however, letters were used instead of squares.

scenes presented in serial positions 9–16. This avoids the presentation of the target at the beginning of the RSVP stream. Participants were instructed to fixate the center of the screen and to rapidly press the RightArrow key when the white square appeared. They were also instructed to memorize the 16 scenes presented in each trial and were tested on scene recognition after each trial.

2.3.2. Scene recognition task

Following each trial, participants were presented with a test scene and asked to report (by pressing the UpArrow or DownArrow keys) whether the test scene had appeared in that trial. To facilitate comparison of results with previous studies, we used the same procedure as used by Lin et al. (2010). The test scene was presented for 3000 ms or until participants' response. In 50% of trials, the test scene was a scene presented in position 9–16 of the present RSVP sequence. In the other 50% of the trials, the test scene was drawn from the set of scenes not presented in that trial. Of note, the target of the white square detection task did not predict which image would be tested in the scene recognition task and thus any benefit in processing of the scene was task-irrelevant in regard to the detection task.

2.4. Results

Mean performance on the white square detection task was 95.8 ± 0.8% (standard error) indicating that participants complied with the instructions to maintain their attentional focus on the middle of the screen. Results for the scene recognition task are shown in Fig. 2. Hit rate for target-paired images (63.3 ± 2.2% correct) and nontarget paired images (63.4 ± 2.9% correct) were both

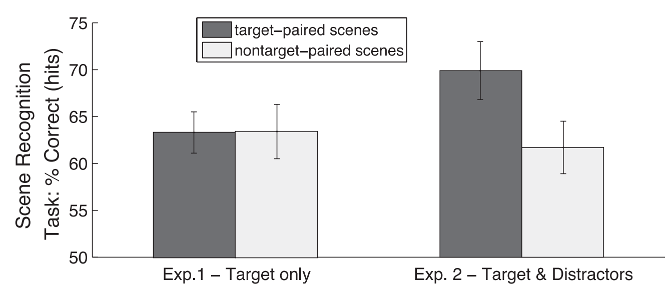

Fig. 2. Results from the scene recognition task of Experiments 1 and 2. Plots represent accuracy (% correct) for Experiment 1 (left panel) and Experiment 2 (right panel). Error bars represent standard error of the mean.

larger than false alarm (FA) rate (36.6 ± 4.3%), respectively $t(15) = 5.48$, $p < .001$ and $t(15) = 8.53$, $p < .001$. A t-test on percent correct (hits) revealed no significant difference between recognition task accuracy for target-paired images vs. nontarget-paired images, $t(15) = 0.72$, $p = .49$. Performance in the recognition test was also assessed by calculating d-prime (d') for each participant. Value of d' were low, indicating a difficult task, however, t-test on d' revealed no difference between target-paired image d' (0.69 ± 0.14) and nontarget-paired images (0.53 ± 0.09), $t(15) = 0.90$, $p = .34$ (to achieve normality for t-tests on d', values are mapped back on percent-correct values on the assumption of an unbiased criteria). Thus we failed to reproduce the findings of previous experiments of fast-TIPL, which demonstrated that very similar procedures resulted in enhanced memorization of target-paired images (Lin et al., 2010; Swallow & Jiang, 2010, 2011).

How can this failure to find fast-TIPL be understood in the context of previous positive findings? We observed that a key difference between this experiment and previous studies was that no distractors were presented in the detection task. Without distractors, only one image was presented with a square, whereas other images were presented with a fixation cross. Thus, the onset of the target was sudden and may have lead to an exogenous orienting of attention to the center of the display. We suggest that this capture of attention disrupted the observation of TIPL because the effect of attentional capture (drawing resources away from the target-paired image) was opposite to the effect of TIPL (enhanced processing of target-paired images). Put together the effects of TIPL and attentional capture could cancel, and then no difference between target-paired and nontarget-paired images would be observed. We thus hypothesized that if distractors were added to the detection task then the abrupt target-onset would be ameliorated and fast-TIPL would be found. To test this hypothesis we conducted Experiment 2.

3. Experiment 2

Experiment 2 used similar procedures as Experiment 1, but distractors were presented with the scenes that were not paired with the target. If the failure to find fast-TIPL in Experiment 1 was related to the sudden onset of the target, then in Experiment 2, where the onset of the target was not sudden, due to the presence of distractors, target-paired images should be better recognized than distractor-paired images.

3.1. Methods

Sixteen new participants (19 y.o. ± 10 months; 10 females, 6 males) participated in this experiment. Procedure, apparatus, and stimuli were the same as described in Experiment 1 with the exception that a black square (luminance of 0.25 cd/m^2) was presented in the middle of the gray aperture with each of the 15 nontarget-paired scenes. As scenes, each square was presented 133 ms, followed by a blank ISI (with no fixation cross) of 367 ms for a SOA of 500 ms (Fig. 1B).

3.2. Results

Mean performance on the white square detection task was 95.1 ± 0.9% indicating that participants complied with the instructions to maintain attentional focus on the middle of the screen. Results for the scene recognition task are shown in Fig. 2. Hit rate for target-paired images (69.9 ± 3.1% correct) and distractor-paired images (61.7 ± 2.8% correct) were both larger than FA rate (38.3 ± 4.4%), respectively $t(15) = 6.12$, $p < .001$ and $t(15) = 7.97$, $p < .001$. A t-test on percent correct revealed a significant difference between recognition task accuracy for target-paired images vs. distractor-paired images, $t(15) = 2.56$, $p = .022$. t-Test conducted on d' produced similar results, with a significant larger d' for target-paired images (0.85 ± 0.15) than for distractor-paired images (0.63 ± 0.08), $t(15) = 2.39$, $p = .019$. The results of this experiment corroborate the hypothesis that the sudden onset of the target disrupts fast-TIPL.

To assess whether the different results between Experiments 1 and 2 were due to an enhancement in memorization of the target-paired images or a reduction of processing of the distractor paired images, we compared the results obtained in the scene recognition task of Experiment 1 and Experiment 2. t-Tests on percent correct (hits) indicated better performance for target-paired images in Experiment 2 than Experiment 1 ($t(15) = 2.17$; $p = .047$), but no difference for the distractor-paired images between the two experiments ($t(15) = 0.34$; $p = .99$). These data suggest that the better performance for target-paired images in Experiment 2 are better explained by enhancement of memorization of target-paired images, rather than a masking of distractor-paired scenes by the distractors.

While Experiment 2 confirmed that presence of distractors is necessary to observe TIPL, we felt that a replication of the effect with a different procedure would add confidence to our conclusion that the presence of distractors is needed to find fast-TIPL. Of note, the procedure used in Experiments 1 and 2 was largely based upon the detection task used by Swallow and Jiang (2010). Thus to test whether distractors are necessary to observe TIPL, we examined (in Experiments 3 and 4) fast-TIPL in the context of the RSVP letter identification task used in other studies of TIPL (Lin et al., 2010; Seitz & Watanabe, 2003; Watanabe et al., 2001).

4. Experiments 3 and 4

In Experiments 3 and 4, we employed the letter target identification task used by the fast-TIPL study of Lin et al. (2010) and as used in previous studies of slow-TIPL (Seitz & Watanabe, 2003; Watanabe et al., 2001). There are two differences between this task and the white square detection task used in Experiments 1 and 2. First, instead of simply detecting the white target, participants were required to determine the identity of the target-letter. Second, the letter identification task involves a delayed report of the target-letter (and an additional memory component), rather than the immediate report of the white square. As in the previous experiments, in Experiments 3 and 4, 16 images were presented per trial. In Experiment 3 (no distractors), only one image per trial was paired with a letter (i.e. the white target-letter). In Experiment 4 (with distractors), one image was paired with the white target-letter and the other 15 images were paired with black distractor letters.

4.1. Methods

Sixteen new participants (19 y.o. ± 10 months; 9 females, 7 males) participated in Experiment 3 and 16 other participants (19 y.o. ± 1 y.o.; 7 females, 9 males) participated in Experiment 4. Procedure, apparatus, and stimuli were the same as described in Experiment 1 with the exception that the letter target identification task (described below) was used the place of the white square detection task.

4.1.1. Letter target identification task

In these experiments the target was a white letter (courier name, 26 font size). In each trial, a white target-letter (identity of target-letter was randomized across trials) was presented in the middle of the gray aperture for the target-paired scene. In Experiment 3 (no distractors), a fixation cross was presented in the middle of the gray aperture with the 15 nontarget-paired scenes. In Experiment 4 (with distractors), a different black letter was presented in the middle of the gray aperture for each of 15 nontarget-paired scenes with the requirement that no duplicate letters were presented in the same trial. As in Experiments 1 and 2, the white target-letter could only appear concurrently with scenes presented in serial positions 9–16. Participants were instructed to fixate the center of the screen and to search and remember the identity of the white target-letter while memorizing the 16 scenes presented in each trial. At the end of each trial, participants were instructed to type the letter key corresponding to the identity of the white target-letter and then instructed to perform the scene recognition task.

4.2. Results

Mean performance on the letter target identification task was 96.0 ± 0.6% for Experiment 3 and 94.2 ± 0.6% for Experiment 4 indicating that participants complied with the instructions to maintain their attentional focus on the middle of the screen. Results for the scene recognition task are shown in Fig. 3. For Experiment 3 (no distractors), hit rate for target-paired images (62.5 ± 3.7% correct) and nontarget-paired scenes (65.7 ± 3.2% correct) were both larger than FA rate (38.5 ± 3.5%), respectively $t(15) = 9.34$, $p < .001$ and $t(15) = 78.41$, $p < .001$. Also, for Experiment 4 (with distractors), hit rate for target-paired images (70.1 ± 3.6% correct) and distractor-paired scenes (63.6 ± 3.0% correct) were both larger than FA rate (44 ± 4.6%), respectively $t(15) = 7.02$, $p < .001$ and $t(15) = 7.16$, $p < .001$). For Experiment 3, a *t*-test on percent correct did not reveal significant difference between recognition task accuracy for target-paired scenes vs. nontarget-paired scenes, $t(15) = 1.49$, $p = .16$; in fact performance was slightly better for the nontarget-paired scenes. *t*-Test on d' revealed similar result (d' of 0.63 ± 0.07 for target-paired and of 0.74 ± 0.09 for nontarget-paired images, $t(15) = 1.19$, $p = .13$). On the contrary, in Experiment 4 (with distractors), *t*-test on percent correct revealed a significant difference between recognition task accuracy for target-paired images vs. distractor-paired images, $t(15) = 3.05$, $p = .008$ and a similar result was obtained on d' (d' of 0.73 ± 0.12 for target-paired and of 0.53 ± 0.08 for nontarget-paired images, $t(15) = 2.59$, $p = .020$).

To test whether the differences in results between Experiments 3 and 4 were due to an enhancement of target-paired images or impaired processing of distractor-paired images, we compared the results obtained in the recognition task accuracy between these experiments. A *t*-test on percent correct (hits) indicated a trend for greater accuracy for target-paired scenes in Experiment 4 than Experiment 3 ($p = .072$), and no significant difference for recognition task accuracy for nontarget-paired scenes between the two experiments ($p = .32$). This replicates the similar pattern of results in the comparisons between Experiments 1 and 2. Combined, these two sets of experiments indicate that fast-TIPL results in an enhancement of processing for target-paired images rather than a diminishment of processing for nontarget-paired images. This is consistent with models of slow-TIPL (Seitz & Watanabe, 2005, 2009) that propose that TIPL reflects an enhancement of perceptual representations of target-paired stimuli.

Thus, in Experiment 4, we replicated the fast-TIPL effect observed by Lin et al. (2010). Furthermore, the comparison of results between Experiments 3 and 4, replicate the finding that TIPL occurs more robustly when distractors are used in the RSVP tasks. We suggested that the presence of distractors was necessary because without them the onset of the target is sudden leading to an attentional capture that disrupted the observation of TIPL. However, an alternative explanation of our findings is that it is only the presence of the distractors, and not the sudden onset of the target, that is needed to observe TIPL. Thus, to more directly test the hypothesis that it is the sudden onset of the target that disrupts TIPL, one additional experiment was conducted. Experiment 5 was a replication of Experiment 1 (white square target) but in which the fixation point was replaced by a black square. In Experiment 5, the onset of the target was made gradual (a slow change of luminance; see Yantis & Jonides, 1984). If the hypothesis that the sudden onset of the target disrupted TIPL is correct, then in this new experiment, TIPL should be observed for target-paired images.

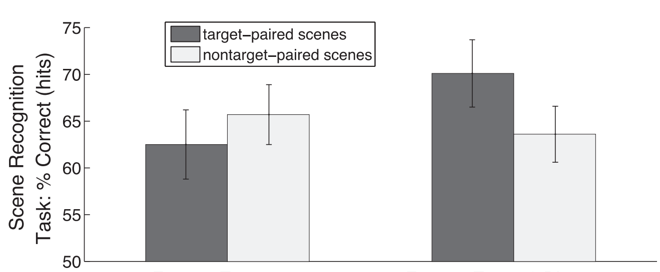

Fig. 3. Results from the scene recognition task of Experiments 3 and 4. Plots represent accuracy (% correct) for Experiment 3 (left panel) and Experiment 4 (right panel). Error bars represent standard error of the mean.

5. Experiment 5

Experiment 5 used similar procedure as Experiment 1 (no distractors, white square target), but the fixation point was replaced by a black square. If the failure to find fast-TIPL in Experiment 1 was related to the sudden onset of the target, then in Experiment 5, target-paired images should be better recognized than distractor-paired images.

5.1. Methods

Ten new participants (25 y.o. ± 5 years; 3 females, 7 males) participated in Experiment 5. Procedure, apparatus, and stimuli were the same as described in Experiment 1, but the fixation cross was replaced by a black square (luminance of 0.25 cd/m^2). In this experiment the onset of the target (white square) was made by a gradual change of luminance between the new fixation point (black square) and the target. The white square target was presented 133 ms, preceded and followed by an ISI of 367 ms, during which the luminance was gradually ramped using an exponential function to that of the black square.

5.2. Results

Mean performance on the white square detection task was 95.7 ± 1.4% indicating that participants complied with the instructions to maintain attentional focus on the middle of the screen. Results for the scene recognition task are shown in Fig. 4. Hit rate for target-paired images (70.6 ± 4.8% correct) and distractor-paired images (60.8 ± 2.6% correct) were both larger than FA rate (28.3 ± 2.5%), respectively $t(9) = 10.73$, $p < .001$ and $t(9) = 15.55$, $p < .001$. A *t*-test revealed a significant difference between recognition task accuracy for target-paired images vs. distractor-paired images, $t(9) = 2.56$, $p = .031$. A similar result was on obtained on d', with a significant larger d' for target-paired images (1.14 ± 0.12) than for distractor-paired images (0.86 ± 0.06), $t(9) = 2.54$, $p = .033$. The results of this experiment corroborate the hypothesis that the sudden onset of the target disrupts fast-TIPL.

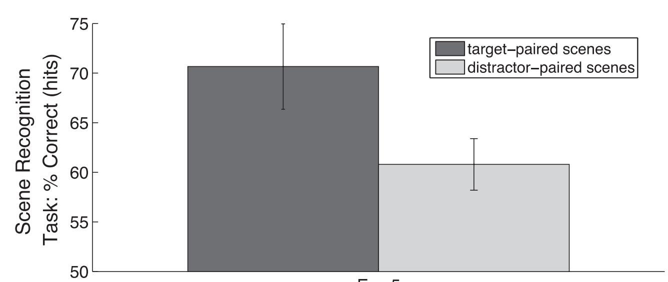

Fig. 4. Results from the scene recognition task of Experiment 5. Plots represent accuracy (% correct). Error bars represent standard error of the mean.

6. Discussion

Our objective was to identify, by using a simple paradigm, the factors key to obtaining task-irrelevant perceptual learning (TIPL). To do so, we used a fast-TIPL paradigm where enhanced memorization of images at behaviorally relevant points in time can be observed on the time scale of a single trial. When experiments were conducted with distractors, fast-TIPL was observed in the form of an enhanced memorization of scenes paired with the task-targets compared to scenes presented with distractors. These results corroborate the results obtained in recent studies of fast-TIPL (Lin et al., 2010; Swallow & Jiang, 2010, 2011), as well as those of slow-TIPL (Seitz & Watanabe, 2003, 2005, 2009; Watanabe et al., 2001). However, when no distractors were presented, fast-TIPL was not found, in that no enhanced memorization was observed for target-paired scenes. This requirement for distractors in the present studies supports our hypothesis that the sudden onset of task-targets can disrupt TIPL.

The disruption of TIPL by sudden target onset is in accord with many studies demonstrating that sudden onset attracts attention. For example, Yantis and Jonides (Jonides & Yantis, 1988; Yantis & Jonides, 1984) showed that the detection of a target was enhanced when the target's onset was abrupt, but not when the target consisted of a change in color. In our experiments without distractors (Experiments 1 and 3) the target appears in the location of the fixation cross. The onset of this new object would attract attention to a greater extent than in the experiments with distractors (Experiments 2 and 4), where the target, square or letter, appeared on the location of another square or letter. To control for the sudden onset hypothesis, a final experiment was conducted in which the sudden onset was ameliorated by ramping the contrast change (procedure adapted from Yantis & Jonides, 1984). The result of this experiment without sudden onset of the target supports our hypothesis that it is the sudden onset of the target that disrupts the observation of fast-TIPL.

A key issue in the interpretation of these results is that the sudden onsets of the targets (in Experiments 1 and 3) would leave less attentional resources available to process the target-paired images than the nontarget-paired images. In the framework of this hypothesis, it could be expected that the recognition task accuracy for target-paired images would be inferior to the recognition task accuracy for nontarget-paired images. However, the results of experiments without distractors indicated no difference in accuracy between target-paired and nontarget-paired images. A possible explanation for the observed finding is that while attention draws resources away from the target-paired images, that fast-TIPL is still taking place and giving some benefit to the memorization of those images. These two effects may cancel out yielding an absence of any net change. It has been previously suggested that attention and TIPL may act in such a complementary way (Nishina et al., 2007), however, future studies will be required to more directly address this hypothesis.

It could be argue that the failure to find fast-TIPL in the experiments without distractors might be related to masking. Indeed, in these experiments, enhanced memorization of the target-paired images would not be observed if the target masked the target-paired images. If such masking explained our results, then identification accuracy for the nontarget-paired images would be expected to be higher in the experiments with no distractors compared to those with distractors. However, this was not the case. On the contrary, we obtained a better recognition for target-paired images in experiments with distractors than in experiments without distractors. Thus, an explanation in terms of masking seems unlikely.

A notable aspect of these fast-TIPL experiments is that enhanced memorization was found for target-paired images that are very salient (i.e. high-contrast without noise). At first glance this seems to run contrary to the observation that TIPL has been found to be related to the signal strength of the irrelevant stimuli. When task-irrelevant stimuli are weak, TIPL is consistently observed, but, when task-irrelevant signals are strong, TIPL is not consistently observed (Tsushima, Seitz, & Watanabe, 2008). An explanation of this dependence of TIPL on the signal strength of the task-irrelevant stimuli is that weak task-irrelevant signals fail to be "noticed", and to be suppressed, by the attention system and thus are learned, while stronger stimulus signals are detected, suppressed (Tsushima, Sasaki, & Watanabe, 2006), and are not learned. A key part of this explanation is that the task-irrelevant stimuli are distracting to the subject's primary task and thus there is a task-advantage to suppressing the processing of these stimuli. Along these lines, studies of TIPL have even found that impairment of learning for stimuli for which attention is exogenously directed (Choi, Seitz, & Watanabe, 2009). However, in TIPL studies mediated by reward pairing, and in which there was no training task, TIPL was found for suprathreshold stimuli (Seitz, Kim, & Watanabe, 2009), presumably because there was no need to suppress these stimuli. Likewise, in the present studies of fast-TIPL, where learning is found, subjects were required to perform a dual-task and thus were required to attend to the scenes. We thus suggest that in cases where the target-paired stimuli have importance to the observer, or when these are not distracting to another task, there is no requirement to suppress salient stimuli and that TIPL will occur.

An important question is whether the enhanced memorization of the target-paired images observed in our study represents a true form of perceptual learning. Perceptual learning has been defined as "any relatively permanent and consistent change in the perception of a stimulus array following practice or experience with this array" (Gibson, 1963). Many, perceptual learning procedures involve weeks or more of training (Furmanski, Schluppeck, & Engel, 2004; Li, Klein, & Levi, 2008; Schoups, Vogels, & Orban, 1995; Schoups et al., 2001; Seitz, Kim, & Watanabe, 2009; Watanabe et al., 2001, 2002) and thus perceptual learning is usually thought to be distinct from studies of short-term memory, which are studied on a much faster time-scale. However, not all forms of perceptual learning are slow to arise. Specific learning can be obtained with a single target exposure (i.e., the phenomenon of one-trial learning preliminary obtained in animals; Sahley, Gelperin, & Rudy, 1981). In humans, abrupt learning of a stimulus can occur after the presentation of a "simple version" of the stimulus (Ahissar & Hochstein, 1997; Rubin, Nakayama, & Shapley, 1997) and there are a variety of paradigms in which stimulus specific perceptual learning effects arise very rapidly (Agus, Thorpe, & Pressnitzer, 2010; Hawkey, Amitay, & Moore, 2004; Poggio, Fahle, & Edelman, 1992). Thus a very plausible explanation of our results is that the perceptual representations of the target-paired images are enhanced through our procedure. However, the current results cannot distinguish this from the alternative explanation that mechanisms related to TIPL serve to facilitate the storage of the target-paired images into memory. Thus while we suggest that fast-TIPL and slow-TIPL are related phenomenon, future research will be required to better understand what differences may exist between them.

7. Conclusion

The paradigm of fast-TIPL, in which enhanced memorization is found for target-paired images on the time scale of a single trial, shows great promise as a method to understand the mechanisms of perceptual learning. In the present study, we found that sudden onset of targets impaired TIPL. We conclude that the fast-TIPL paradigm is a useful method by which to investigate the mechanisms that lead to TIPL. Further research will be required to gain a more detailed understanding of the processes involved in TIPL and the relations between fast-TIPL and slow-TIPL.

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